Man-Man-Machine-Machine Etiquette: Towards an Environment to Investigate Behavioral Rules for Dynamic Man-Machine Teams

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SUMMARY

In order for a defense organization to gain understanding of their performance in complex tactical situations it is important to accurately model the way opposing and own forces operate. It is a significant challenge to develop such models due to the increasing interdependence between personnel and technology. To gain a clear insight in how personnel and technology (or a man-machine network) together influence operational effectiveness one has to model environment, systems and human behavior at a very detailed level. TNO is performing research focused on maintaining or improving operational effectiveness with the introduction of new technologies such as smart sensors and unmanned systems. Simulation developers face the challenge of coupling environment, sensor, system and human behavior models in order to perform such research. There are currently not many standards and tools that support this kind of coupling, especially in the area of man-machine collaboration. TNO is developing the Man-Man-Machine-Machine Etiquette (M4E) toolbox that helps in integrating models of man and machine and allows them to run in concert in a simulated environment.

1.0 INTRODUCTION

Defense organizations are looking for ways to improve their performance. Much time and effort is spent on training of personnel, and research and money on the development or acquisition of new technologies. To investigate in how far these efforts lead to improved performance, experimentation is required. Because real-world experiments are often difficult to organize due to issues of safety, logistics and money, many experiments take place in simulated environments. To gain a good understanding of performance in complex tactical situations it is important to accurately model the way opposing and own forces operate. It is a significant challenge to develop such models due to the increasing interdependence between personnel and technology. The pace of technological innovation is still increasing exponentially and it is becoming more difficult to leverage technological innovation on the battlefield. Additionally, due to the increase of technology in the environment of the operator, the task of operators is shifting from procedural oriented tasks towards resource management and decision making tasks. To keep track of how personnel and technology (or man-machine network) together influence operational effectiveness one has to model, environment, systems and human behavior at a very detailed level. We call the search for the optimal way for man and machine to collaborate the search for the optimal man-man-machine-machine etiquette (M4E).

TNO is performing research focused on improving or at least maintaining operational effectiveness with the introduction of new technologies such as smart sensors and unmanned, autonomous systems. To perform such research in a simulated environment, simulation developers face the challenge of coupling environment, sensor, system and human behavior models. There are currently not many standards and tools to support this kind of coupling, especially not in the area of man-machine collaboration. While there are standards for certain types of models (e.g. DIS, HLA, FIPA, TCP/IP, XML) [1] there is no standard to

[1] DIS: IEEE Standard 1278, HLA: IEEE 1516-2010, FIPA: www.fipa.org, TCP/IP: RFC 1122, XML: www.w3.org/XML/

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14. ABSTRACT
In order for a defense organization to gain understanding of their performance in complex tactical situations it is important to accurately model the way opposing and own forces operate. It is a significant challenge to develop such models due to the increasing interdependence between personnel and technology. To gain a clear insight in how personnel and technology (or a man-machine network) together influence operational effectiveness one has to model environment, systems and human behavior at a very detailed level. TNO is performing research focused on maintaining or improving operational effectiveness with the introduction of new technologies such as smart sensors and unmanned systems. Simulation developers face the challenge of coupling environment, sensor, system and human behavior models in order to perform such research. There are currently not many standards and tools that support this kind of coupling, especially in the area of man-machine collaboration. TNO is developing the Man-Man-Machine-Machine Etiquette (M4E) toolbox that helps in integrating models of man and machine and allows them to run in concert in a simulated environment.

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couple the different types of models. This means that for each new man-machine network under investigation the simulation developer has to develop a simulation environment nearly from scratch, because existing systems are not transparent, not open or simply too monolithic. This is hindering the amount of re-use that is potentially possible. This in turn is lengthening development time and therefore driving up costs of research. Ideally one would just spend time on measuring relative effectiveness of different uses of novel systems. Currently much effort goes into the building of the infrastructure that makes experimenting possible.

Because the simulation developers can not easily re-use model couplings, the lessons learned are not anchored in technology. If each new project develops new simulation technology the wisdom of previous generations is lost. Therefore there is an increased risk of repeating the same mistakes. Additionally, the fact that current interoperability standards are monodisciplinary (i.e. coupling only simulation, or only agents) means that there is little opportunity for researchers to explore multidisciplinary approaches.

TNO undertakes multiple projects that require the coupling of diverse models. Therefore, the burden of the previous mentioned issues is strongly felt. To alleviate these issues TNO is developing the M4E toolbox to help with integrating diverse models and to allow them to run in concert in a simulated environment.

Each investigation into man-machine networks has a specific focus and it is therefore not possible to completely standardize the way to build a composite system of diverse models. We therefore propose not to aim for standardization, but to aim for facilitation. Our goal is to provide tools that offer a way to couple systems using standards if possible, to offer template programs where it is useful, and to leave undefined those things that are specific to a research project.

1.1 Related Work

Much research has been done on developing simulations that provide insight in operational effectiveness and on how this can be improved. Such research is widespread both within TNO and internationally. The man-man-machine-machine etiquette approach aims to harmonize a number of research areas.

One of the relevant areas is the relatively new research field concerned with heterogeneous forms of simulation. TNO has investigated ways to combine Live simulations (real people and real systems) with Virtual simulations (real people, simulated systems) and Constructive simulations (simulated people, simulated systems) [11]. Such a combination could provide additional flexibility of simulations. Important research issues in this area are how to ensure the effective sharing of data between simulations, and how simulations could best interoperate.

A similar issue arises in the area of joint simulation, in which multiple simulation platforms, frequently from various (parts of) defense organizations, are coupled. Joint simulation is valuable because it can create realistic training situations that specifically address collaboration issues between countries. Again effective interoperability of all the participating simulated systems is key to tap this potential value [12].

The same issue again rises when combining separately developed simulations to prove a concept. At TNO research is done to test novel sensors (or sensor simulations) and their effectiveness in operational settings [5]. The value of a sensor can be determined by applying the sensor in multiple contexts (e.g. does a camera sensor work equally well on land as on water). Simulating these contexts is a cost effective way to test this. However, this requires that a sensor can interoperate with multiple simulations.

In applied research often such interoperability issues arise, e.g. when asked to investigate a specific issue as “how do I best protect a compound” or “how do I defend best against mortar attacks”. Pragmatics demand that one does not build all required simulations from scratch but starts a search for relevant existing systems. Next step is to combine those systems and start a simulation based analysis of the issue.

When creating such a composite simulation system again interoperability is a key issue. At TNO the experience is that even with current available standards (i.e. DIS, various HLA flavors) it is still a significant effort to harmonize simulations.

The above examples show a trend towards increased use of (widely) distributed systems. TNO is at the forefront of this development [13]. For example, there is an ongoing effort to investigate distributed sensor systems and sensor networks. Such networks of sensors create value because by (intelligently) fusing the sensor data more informative results can be extracted out of relatively simple sensors. However, it is not trivial to answer the question on how and what sensors should communicate amongst themselves to yield the most useful and usable sensor data.

A specific example of a distributed system is a simulation in which agent technology is used to simulate human (cognitive) behavior. TNO has performed research into using intelligent agents to generate behavior that can be used both for training [14] and decision support [15]. Intelligent agents can greatly improve the functionality of virtual training systems and help support tactical operations. Commonly advanced agent systems run as a distributed system where agent behavior is performed on a specific agent simulation platform and the virtual environment is simulated on a separate platform. Again the question on how and what should be communicated between these systems is not trivial to answer.

One new area of research is the mediation of machine expertise with human users through natural communication (e.g. speech and dialog) [16]. Such advanced man-machine interfaces (MMI) can greatly improve the usability of highly automated systems. For example, TNO is working on Ashley. Ashley is a novel type of interface that offers an intuitive way to communicate with many machines through intelligent dialog and speech. In this approach it is essential that Ashley can reason about the machines and capabilities that she represents towards the user. One key aspect is to determine how machines and Ashley communicate to establish what Ashley can do for a user. Similar issues arise with other advanced interfaces, such as an adaptive task allocation interface between a user and automated support systems.

Internationally there is much related work being done on man-machine networked operations. In [5] an argument is put forward to use man-machine network simulations to investigate the benefits of autonomous systems in both civilian and military organizations. Many similar studies support this argument and report increased need for autonomous systems to improve operations and reduce casualties, see for example [6],[7],[8] and [9]. However, the authors of [5] do not go into detail on how the creation of man-machine simulations can be supported. Zülch and Becker [3] present an integrated system that can help determine the optimal leverage of men and machines in manufacturing processes. The system is supported by a constructive simulation of both personnel and machines. Such a constructive approach has the advantage that all simulation is done in one monolithic system which simplifies the development of the simulation. The drawback is that it is computationally limiting to model such a complex simulation in one monolithic system. Due to the computational limitation the resulting simulation is therefore inherently abstract and limited in detail. In [4] an example of a human-machine network simulation (air MIDAS) is described to investigate errors in aviation operations. The air MIDAS simulation again is a tightly coupled system of environment simulation, behavior models and system models. It would be beneficial if parts of the system could be re-used (e.g. the behavior models) or if other parts could be flexibly inserted.

Summarizing, man-machine network simulation requires expertise from multiple disciplines and flexible integration of models, which remains a key challenge. With the M4E approach we try to address this issue by a) facilitating re-use of simulation models, b) proposing a flexible way to create man-machine network simulations and c) preventing researchers to have to start from scratch by offering systems that can function as a starting point to develop a new man-machine network.

2.0 SIMULATING MAN-MACHINE NETWORKS

To analyze complex organization such as military units, business organizations, and crisis organizations one needs to at least take into account: the environment of the organization, the information that is available (for instance via sensors), the information systems that are used, and of course the human resources of the organization. This essentially describes a complex man-machine network operating within an environment.

To create a simulation for this analysis, one needs the following components: an environment simulation, a sensor simulation, models of the information systems, and either human behavior models or user interfaces (for human-in-the-loop simulations). All these components are placed in a network and each network node is connected to all others, see Figure 1.

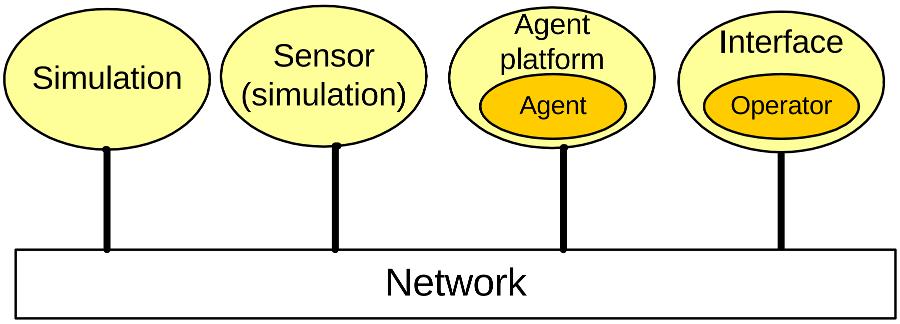

Figure 1: Man-Machine network components.

There are many kinds of simulated environments (e.g. live, virtual, constructive, games). An environment simulation must at least be able to perform simulated commands and deliver relevant world information to other network nodes. The challenge is to avoid the effort of creating new network couplings between each simulated environment and the other parts of the human-machine simulation network.

There are also many types of sensors and in some cases one ‘sensor’ consists of an entire network of smaller sensors. The key requirement of a sensor in a man-machine network is that it must be able to send sense data across the network. However, the nature of sense data varies greatly among sensors (in type of data, frequency and complexity). The challenge is therefore to flexibly federate sensors with the other nodes of the network.

Information system simulations again are available in great variety. At TNO we have a strong interest in support systems for operators as well as in human behavior simulations. Both information systems are usually modeled in the form of intelligent agents. For a human-machine network simulation an intelligent agent should be able to receive information and produce appropriate actions. In other words, an agent must be able to execute relevant tasks and, in so far the agent represents a man or machine that is part of a team, it must be able to communicate about those tasks with other agents and with human operators. The challenge therefore is to create a way of communication that is transparent for both machine-machine connections and man-machine connections.

The man-machine interface (MMI) is the primary way for human users to access the network. All other components are part of the same “world” from the perspective of the user. The challenge is to create an MMI that can adapt its domain related information presentation to suit the expectations of professional users while keeping consistent those parts of the MMI that concern domain independent interaction. An example of a domain independent interaction could be changing the amount of support the user wants to receive from information systems.

In short, we are trying to define a bridge between the fields of environment simulation, machine perception, intelligent agents and man-machine interfacing. In each of these fields there are (emerging) interoperability standards. However, there is little work being done that integrates these approaches. We propose the M4E approach using the M4E toolbox to construct man-machine networks.

2.1 M4E Approach

To develop the M4E approach we take a representative research challenge, and try to define, partly drawing on lessons learned, what support can be created for the researcher that is developing a man-machine network simulation. In the first iteration we focus on compound protection as a representative field of research. For this case the challenge is to develop a man-machine network that can be used to explore different levels of automation and support for an operator tasked with compound protection.

General Scenario Description

There is a crowd near the fence of a compound. A small number of people behave suspiciously in the sense that they enter the forbidden area. These people are detected by sensors. A threat detector support system (agent) signals the suspicious behavior and informs a command support system (agent) and the human operator (via a MMI). The human operator, supported by the command agent, takes action and, also via the MMI, commands a small quick reaction force (QRF) to arrest the suspicious people. The QRF is simulated and its behavior is controlled by a behavior simulation (agent).

Environment

The environment consists of a compound, which is surrounded by a fence with two gates. Around the fence there is an area where no (external) people are allowed. See below.

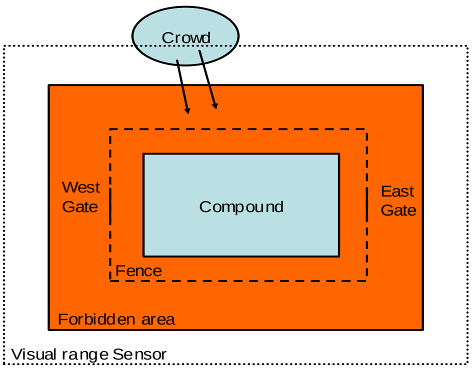

Figure 2: Compound overview.

Units

- A crowd outside the gate, from which two persons (armed with explosives) try to intrude the compound.
- QRF, which consists of a team of 4 that can arrest the intruders.
- Sensor(s), located at the compound. It can distinguish positions of contacts in the area outside the compound till 10 meters outside the forbidden area.
- Threat Detection support system, with whom the human operator through the MMI has made arrangements on when to inform the MMI. This system passes a contact's position to the MMI

and can aid in its identification (based on its intrusion level and whether it is an own force yes/no). We distinguish four identifications (hostile, friendly, neutral, unknown).

- Command support system, that can support the operator in its task to decide on how the handle intruders.
- Human operator, who is responsible for the protection if the compound. The operator identifies contacts and decides how/which intruders to arrest.

Exploration of Different Levels of Support

In this case we want to compare two levels of support for the operator. We offer a low level of support in which the workload of protecting the compound rests mainly with the operator. Alternatively in the condition of high level support the operator is supported in threat detection and resource assignment.

In the ‘low level of support’ condition the Threat Detection support will deliver a limited set of alternatives to the operator. Given the task ‘threat detection’ or perhaps better ‘identification’, the system will provide the positions of contacts, together with the possible identifications (unknown, neutral, friendly, hostile). The operator must then decide which alternative it will be.

In the ‘high level of support’ the Threat Detection support will execute the best alternative. This means it will assign an identification to each contact which can be shown on the MMI.

In the ‘low level of support’ the Command support system will deliver a limited set of alternatives to the operator. Given the task ‘command’ or perhaps better ‘contact handling by arresting’, the system will provide the MMI for detected contacts the possible QRF assignments. The operator must then decide which assignment to make.

In the ‘high level of support’ the Command support system will execute the best alternative if the operator approves. This means it will provide the MMI with the best contact-QRF assignment and the option to confirm this assignment.

With a human-machine network at our disposal that can accommodate this scenario and the different levels of support we can perform a systematic experiment into which level of support is suitable under which conditions for the operator.

Even with a relative simple case as the compound scenario case, the amount and types of data flowing across the man-machine network becomes complex quickly, see figure 3. This underscores the helpfulness of developer tools in creating such networks. In the following section we will describe what tools TNO is creating to support the development of such a network.

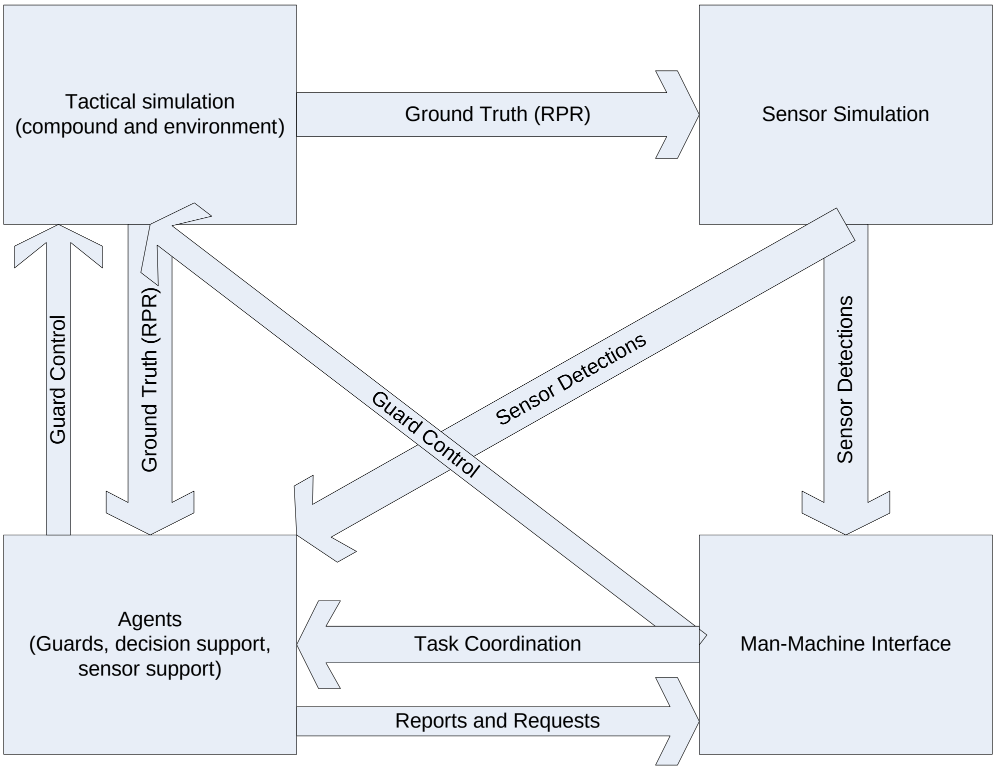

Figure 3: M4E Compound protection case data flow.

3.0 TOOLS IN THE TOOLBOX

Within the M4E project we aim to create man-machine network developer tools that facilitate the creation of such networks for research. In this section we describe the toolbox that contains the results of our effort.

3.1 Simulation Tools

The intent of TNO is to provide an environment for easy development of simulated environments enriched with additional components such as Artificial Intelligent (AI) Behavior. The AI can be created close to the virtual environment or as a separate part. A separate implementation has the advantage of being independent of computing cycles of the simulator and gives the freedom of choosing a programming language. The disadvantage is that you have to transport all information (commands and reports) between the simulated environment and the AI platform.

The interfaces used in M4E aim to be standardized in a way to allow an easy swap between simulation environments (e.g. VR-Forces[2], VBS2[3]) and AI (e.g. Jadex [10]). It is desired to make this interface based on existing standards.

HLA is chosen for the M4E interface. The HLA RPR FOM is a data exchange standard (SISO-STD-001-1999) that has received many followers in the field. While it is a good starting point to define the data that needs to be shared between simulations, it was never intended for a broader scope (including AI or MMI) or a more flexible approach. We propose the take this FOM as a starting point and to extend it with man-man-machine-machine network specific additions.

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[2] http://www.mak.com/

[3] http://www.bisimulations.com/

HLA is also a beneficial choice because the HLA is already a standard in TNO simulation federations. Moreover, the AI architecture under consideration is being prepared with an HLA interface (in the form of a combination between Pogamut[4] and Jadex). The information exchanged in M4-networks will be secured in the M4E-FOM.

HLA Related Choices

HLA is available in three flavors:

- HLA 1.3
- HLA IEEE 1516
- HLA Evolved

HLA 1.3 is the first implementation of HLA. With HLA IEEE 1516 a number of problems found during practical use of HLA 1.3 were solved and it was accepted as a standard. The newest, HLA Evolved, extends HLA with amongst others modular FOM and dynamic link compatibility.

For optimal flexibility HLA evolved is the way to go as this allows federates to only implement and use the part of the FOM that they require. But as this is a very new standard many applications do not comply to HLA evolved yet (e.g. VR-Forces).

For practical reasons the first iteration of M4E will therefore use HLA 1.3. For example, Pogamut is being developed with the portico RTI, only available in 1.3. VR-Forces is available in 1.3 and IEEE 1516. VR-Forces is a product of MaK, so we build on the Mak RTI. In the future M4E will migrate to HLA evolved depending on the available support.

HLA allows for objects and interactions. Interactions are once-only while objects stay alive until deleted.

For tasks and reports both types are possible. When you use objects, the status of the task can be updated. For example, someone sends a report and someone else updates it with executing, or done. But this will add a time-consuming ownership management to the system. It can also be done with interactions. The interactions then need an ID so the response can refer to this ID. For M4E the choice is made of sending tasks and reports over interactions

M4E Specific FOM Definitions

For M4E we have define the following additional classes to the RPR FOM:

Table 1: Additional FOM classes.

	Object Classes	**Interaction Classes**
Task Coordination	TaskDescription, AgentConfiguration, M4ETaskSetting	RequestTaskAllocation, RefuseTaskAllocation, AgreeTaskAllocation
Task Specific	Contact, QRFPersonnel, QRFAssigment	Detection, ThreatLevelOptions, ThreatLevelDecision, QRFAssignmentOptions, QRFAssigmentDecision, Order, MoveTo

4 http://artemis.ms.mff.cuni.cz/pogamut

Depending on the specific man-machine network and the shared task of the man-machine team there will always be task specific adaptations that must be made. This is an unavoidable fact that is part of the reality of doing novel research. However, communication about task coordination and collaboration is a part of the data exchange that we can facilitate by using the Task Coordination classes.

3.2 Man Machine Interface Tools

Humans have been interfacing with simulations since the advent of simulation. However, few human-machine interfaces have been developed that are specifically useful in shaping man-man-machine-machine collaboration. Often simulation interfaces are strictly domain orientedand offer little support for a structured or comprehensive exploration of different collaboration concepts.

Experimenting with man-machine teams often means (re)considering the workload division between man and machine. A very effective research tool is the ability to change such workload divisions across experimental conditions. However, simple changing the workload division means that the user will have a different interaction with the machine. When the workload division changes, the interface should adapt itself to the new type of interaction that results. So there are two main requirements 1) the workload division should be configurable (most likely by the researcher), and 2) the user interface must adapt to a new workload division.

Within M4E we recognize that for most research projects there will always be a domain specific user interface required. However, we can develop a reusable user interface that allows changes in the division of work. Additionally, because we also develop tools for communication (with the M4E addition to the RPR FOM) and templates for intelligent systems we can ensure that such work division changes are easily supported in communication architecture and intelligent system design.

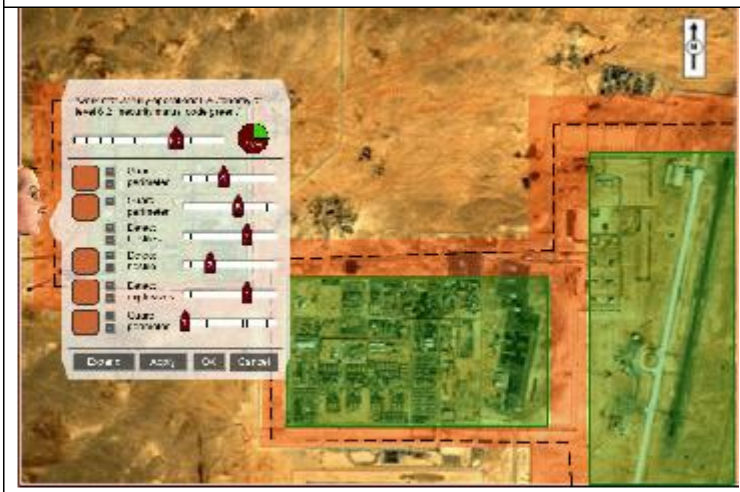
For the collaboration interface we envision a three stage user interface. These stages range from abstract and simple to extensive and intuitive. Depending on the research project one only needs a work division change when the researcher demands it (between experimental conditions). In other cases the researcher may want to experiment with real-time dynamic changes in work division by the operator. By have three stage of the collaboration interface one can pick and choose.

The first stage collaboration interface is a simple pie chart which shows the amount of support that the operator receives from the system, see table 2.

The second stage collaboration interface shows the tasks that need to be performed by the operator and the available support for those tasks. The researcher or operator can specify how much support is required for each task.

The third stage collaboration interface is a fully fledged virtual assistant that can notify and explain the work division options. The virtual assistant is voice controlled and the operator can speak his work division desires and the assistant will execute what is ordered.

Table 2: Three stage user interface for man-machine collaboration.

	Level 1: high-level assistance & control.
	Level 2: low-level assistance & control
	Level 3. Collapsed assistant. Placement represents amount of support (high = high; low = low). Assistance available by single user action (click/tap/speech).

3.3 Sensor Simulation Tools

Sensors have often been developed in isolation. Much work still remains to be done on developing a (military) standard to connect sensors in a network. We propose to integrate sensor and simulation approaches as much as possible. We develop sensor models that produce HLA-RPR-FOM compliant output.

TNO has developed the TActical sensor network TEst bed (TASTE) [2]. TASTE is a simulation platform that can be utilized to simulate novel sensors. TASTE started out as a software tool for specifying and deploying unattended ground sensors (UGS) in a composition which the commander assumes will suit his needs the best. Within TASTE different sensor types such as acoustic, magnetic, seismic, radar and IR imaging sensors can be deployed virtually, and their individual and combined performances analyzed. It is therefore well suited as a platform to investigate sensor networks. Sensors can be deployed in scenarios for neutral, friendly and enemy movements and a set of typical environmental conditions can be selected as input to the simulator. The taste platform is offered in M4E as a convenient way to connect sensor simulations to other simulations, intelligent agents and user interfaces.

3.4 Intelligent Agents Tools

Intelligent agents are a promising area that can contribute much to man-machine network simulations. Up until now most of the agent computing platforms have been developed in isolation (e.g. ACT-R[5], SOAR[6], JADEX). We are extending an existing agent framework to integrate more easily with simulations and sensors. This way simulation developers no longer have to start from scratch when experimenting with intelligent systems in a man-machine network.

We have started out with JADEX as the agent platform based on past experience and the fact that it is an open platform. A recurring problem with agent development is that the link between an agent and the simulated world is often a connection along which information flows that is not standardized in any way. We have extended JADEX with a HLA connection and a way to translate HLA messages to JADEX messages. Agents within JADEX now have a means of communicating across HLA. Additionally we have developed an agent template that can process the M4E FOM messages. This enables an agent to automatically respond to changes in work division. If more intelligent support is needed, (sub)tasks are transferred to the agent and the agent changes the way in which it communicates. This way support system, user interface and simulation all can work in concert to adapt the simulation to different ways of working.

We have created a flexible way of dealing with (dynamic) work division between man and machine. Central to this approach is the shared task (or shared goal) of the man-machine network. Both the machine side as the human side must agree on a) what it is that needs to be done, and b) how the task can be decomposed and delegated. For this we propose a three type categorization of tasks.

Table 3: Different task classes.

Task Type	Description
Atomic	Atomic tasks can not be subdivided and are always performed by either a man or machine. When delegated they are delegated in their entirety.
Mixed	Mixed tasks is collection of subtasks that can be a mix of atomic and M4E subtasks. Usually this is the type associated with the shared goal or overall task of the man machine team.
M4E	This type of task is structured in three distinct subtasks: suggest, decide and act. This type of task can be executed in a shared fashion between man and machine. The subtasks must be performed in order.

[5] act-r.psy.cmu.edu

[6] sitemaker.umich.edu/soar

The M4E task type allows us to create a system of collaboration while still leaving room for other types of task structures. The research retains freedom of choice in this regard. However, M4E offers advanced collaboration support for tasks that are structured along the M4E type structure.

Usually, when man-machine collaboration is discussed the 10 point scale of Parasuraman, et al. [17] is referenced to denote the amount of work assigned to man or machine. We posit that this scale confuses work distribution and communication about the work itself. For the M4E task type we have created a new work division concept that explicitly decouples work division from communication about the work.

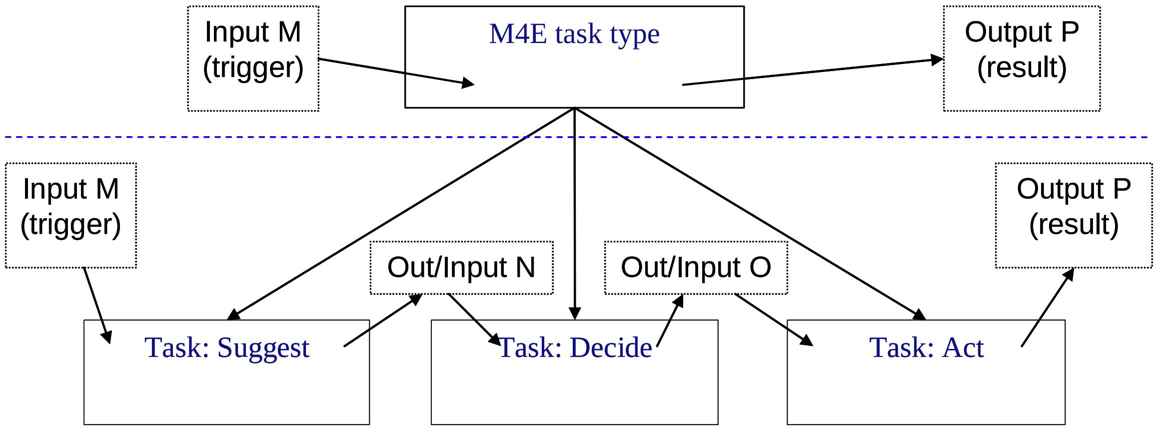


Figure 3: M4E task type.

Figure 3 shows that a M4E task needs input (M) to activate and results in output (P). At this level the choice is only whether or not to share the output with the other members of the man-machine network. However, if we observer one layer deeper we can see that the output from the suggest sub-task (N) and the decide sub-task (O) can potentially also be communicated. For example, consider an M4E task that is shared between man and machine where the machine is responsible for the suggest sub-task and the human for the decide and act sub-tasks. In this case the machine necessarily needs to communicate N to the human so that the decide and act sub-tasks may be executed. Output O is not communicated at all since this output only exists in the mind of the human. The human finally produces output P. This example shows that communication about the task follows naturally from the division of work. This makes it possible to prepare an intelligent agent “template” that follows this structure and automatically adapts communication rules to changes in work division in the human-machine network.

3.5 Domain Knowledge Tools

One of the key issues when building a man-machine network is to make sure that all personnel and machines collaborate on the same shared mission. However, in a man-machine network simulation a lot of different parts need to work in harmony. This poses a risk that the different parts may not agree on the shared mission and start to work past each other. In the M4E toolbox we provide a generic way to structure the mission or task under investigation that enables simulated environment, sensor, agents and man-machine interfaces to work in concert and keep them aligned on the same mission.

Because HLA supports persistent shared data models it is relatively straightforward to publish a task-ontology throughout the man-machine network. We have defined the following object classes for this purpose.

Table 4: This table shows the classes used to share task and work division information.

Classname	**Attribute**
TaskDescription	Taskid
	Description
	Type
	SubTasks
AgentConfiguration	Agentid
	Name
	SupportedTask
M4ETaskSetting	TaskId
	M4EType
	Agent1Id
	Agent2Id

The task description objects define the shared mission (main task) and all the underlying subtasks. The agent configuration objects are used to signal which man-machine team members can perform which tasks. Finally, the task setting objects are used to signal across the entire network how the work is divided at any moment. The machine part (i.e. the agents) of the man-machine network can assimilate this task ontology without translation. The human part has to be supported by the MMI to provide insight in the task. Additionally, the MMI will need to translate human capabilities in terms of agent configuration in order for the machine part to know what the human part can do.

4.0 DISCUSSION AND FURTHER WORK

In this paper we have described the tools that are the part of the M4E toolbox. As we stated in the introduction, man-machine research project often start from scratch or with very little re-use of systems. As a direct result from M4E there are now HLA object classes defined that offer a way to communicate about task coordination and collaboration suitable for any domain. These have been implemented and are ready to be (re)used across multiple research projects.

If there is little re-use then lessons learned are not anchored in technology across projects. M4E allows better transfer of lessons learned about work division by defining an information exchange contract with respect to man-machine collaboration. If M4E is successful and multiple project use the information exchange contract and extend it then there is even more potential to “stand on the shoulders of others”.

We put forward in the introduction that a lack of standards to federate heterogeneous models is impairing innovative new simulation concepts. We have shown that in the M4E vision we aim to leverage the strength of specific models by composing a system from distributed models. Furthermore, we propose to improve that strength by specifying standards that regulate how models can work together (such as in the case of work division).

Developing a man machine network is inherently complex and therefore benefits from developer tools that speed up their creation. With M4E we have provided tools for simulation, sensor simulation, man-machine interfacing, intelligent systems design and domain knowledge sharing to facilitate the creation of such a network. This will reduce the burden on the researchers and developers in creating the necessary experimental setup that they require to create insight in man-machine networked operations. The toolbox will shorten development time and will help keep the focus on the operational research questions.

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